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Analysis and Design of Electrical Transmission Towers with Various Sections and Bracing Configurations

Md Ilyas[1], Prof. Rajkumar Tadkal[2]
[1]*PG Student, Dept of Civil Engineering, PDA College of Engineering, Kalaburagi, Karnataka, India*
[2]*Assistant Professor, Dept of Civil Engineering, PDA College of Engineering, Kalaburagi, Karnataka, India*

Abstract: This study focuses on the analysis and design of a 400kV electrical transmission tower with a height of 50 meters. The tower was modeled in STAAD.PRO using three distinct steel sections Angle, Tube, and Channel combined with various bracing configurations, including X, K, and D-bracings. The main objective of this study is to determine the most efficient and economical configuration for the design of Transmission tower. The tower is analyzed for Dead load, Live load and wind load as per the codes. The study concludes that transmission towers with angled sections and X-bracing exhibit moderate displacement, minimal reaction forces, and reduced structural weight, making them a preferred design choice. Manual calculations were performed to design the connections and footing, ensuring structural integrity. The results confirm that the tower's connection design is safe and reliable.
Keywords: Transmission tower, STAAD.PRO, 'X' 'K' & 'D' bracing, wind forces, Connection design

I. INTRODUCTION

Transmission towers, commonly referred to as power towers or electricity pylons, are critical structures that support overhead power lines. They enable the transmission of high-voltage electrical energy from power plants to substations across long distances, ultimately supplying electricity to homes and businesses. Typically constructed from steel, these towers are designed to withstand a variety of environmental challenges, including strong winds, ice loads, and the weight of the cables they carry. They come in different configurations such as lattice, tubular, and monopole designs, each suited to specific voltage levels and terrain types. Key components of a transmission tower include the main structural body, insulators to prevent electrical leakage, cross arms for mounting conductors, and grounding systems for safety. Strategic placement of these towers ensures the integrity and efficiency of the power grid while minimizing environmental impact. Regular maintenance, including inspections and protective coatings, is crucial to maintaining their structural health and ensuring a reliable electricity supply. In summary, transmission towers are fundamental to the electrical infrastructure, facilitating the dependable and efficient distribution of electricity that supports modern society and economic growth.

II. LITERATURE REVIEW

Sai Avinash P [3] (Analysis and Design of Transmission Tower using STAAD.PRO). This thesis investigates the design of a 49-meter-tall transmission tower, using STAAD.PRO to support a 220 kV double circuit cable. To ensure a safe and cost-effective design, both structural and electrical considerations are addressed. In compliance with IS 800-2007 standards, wind forces are identified as having a significant impact on the tower's self-weight, as well as on the conductors, insulators, and the tower structure itself. The study focuses on optimizing the tower by incorporating X and K bracings and using different steel sections, all analyzed through static analysis. The findings reveal that modifying the bracings and steel sections leads to a notable 6% reduction in the tower's weight, achieved through improvements based on displacement values. This optimization contributes to a more efficient and economical design for transmission towers.
Jyoti Besra [5] (Analysis and Design of Transmission Tower using STAAD.PRO V8I) This study presents a structural analysis and design of a 40-meter transmission tower with X-bracing, utilizing STAAD Pro V8i. The tower is modeled using Indian angle sections based on the properties of its elements. Various load combinations were analyzed, with wind forces being the most critical. The analysis also assessed maximum displacements at different nodes and under varying load conditions to evaluate the tower's response.

These displacement values assist engineers in determining if the structure can safely withstand the applied loads without undergoing excessive deformation or risk of failure. By ensuring the displacements remain within acceptable limits, the design ensures the tower's structural integrity under operational conditions, providing both safety and reliability for its intended purpose.

Sniawlangki T Chyrmang [7] (Analysis of Transmission Tower) This paper examines 400 kV double circuit transmission line towers, or suspension towers, using STAAD.PRO V8i SS5. The analysis incorporates forces such as wind load per IS 802 (Part I/Sec 1):1995, dead load, and earthquake load per IS 1893 (Part 1):2015. The towers, with a height of 50 meters and a base width of 10 meters, are located in seismic zones and divided into wind zones 2 and 6. Angle sections are used, with X and K bracing systems considered. The study concludes that towers with X bracing offer a 3.07% reduction in steel weight compared to those with K bracing, making X bracing more cost-effective. Despite the higher base shear in wind zones, both bracing systems show minimal differences in deflection under various loads.

Dr. S. A. Halkude [11] (Analysis and Design of Transmission Line Tower 220KV: A Parametric Study) This study explores optimizing the geometric configuration of a self-supporting 220 kV transmission line tower by analyzing various parameters such as the width-to-height ratio, bracing systems (X, K, XBX), and the number of panels in the tower body. The tower, designed at a constant height of 20 meters, considers consistent load parameters, including wind forces per IS: 802 (1995), and adheres to uniform clearances, spans, conductor, and ground wire specifications. The research focuses on evaluating slenderness effects, critical sections, forces, deflections, and overall tower weight. A comparative analysis reveals that X bracing offers space efficiency, reducing base width by up to 55% compared to XBX and K systems, making it ideal for land-constrained areas. However, X bracing becomes less economical when the width-to-height ratio exceeds 0.139, leading to increased tower weight by 3% to 13%. The study emphasizes the impact of axial forces and displacements on the structural performance and stability of various bracing systems.

A.Jesumi [13] (Optimal Bracing System for Steel Towers) This study evaluates various bracing configurations—X-B, single diagonal, X-X, K, and Y bracings—for their cost-effectiveness in steel lattice towers with heights of 40 meters (13 panels) and 50 meters (16 panels).Only 28–30% of the towers are straight, and the remaining 70–72% are tapered. Wind loads in vertical, normal, and parallel directions were examined using IS: 875-1987 Part 3 as a basis. Maximum loads occurred under diagonal wind conditions. Taking into account the wind both normal and diagonal to the tower face, the towers were evaluated under two load combinations: dead load (DL) and wind load (WL). A comparison of various bracing styles and their associated weights and joint displacement showed that, up to a height of fifty meters, Y bracing is the most economical option.

III. OBJECTIVES

1) To Conduct a comprehensive assessment of the structural performance of transmission towers.
2) Investigate and compare different configurations of bracings (X, K and D bracing) to identify optimal design that minimize material usage while ensuring structural integrity.
3) Analyse the cost implications associated with different tower sections and bracing configurations.
4) Design of Connections using relevant data from analysis.

IV. METHODOLOGY

To design a 50m transmission tower, first determine key parameters including capacity of the tower, terrain, and climatic conditions using IS 875 Part 3 for wind pressure and IS 802 for load specifications. Ensure minimum ground clearance as per IS 5613 and consider ACSR conductor specifications from IS 398. Model the tower using STAAD.PRO with various steel sections (Angle, Tube, Channel) and bracing types (X, K, D) to create nine different models. Define the geometry, assign material property and section properties, apply loads, and set support conditions. Analyze the structure for forces and moments, then design members and connections as per IS 800:2007, optimizing sections and preparing detailed reports.

A. Transmission Tower Geometry

Table 1: Transmission tower dimensions

Specific Height	Linear distance(m)
Total Height (H)	50.0m
Base Width (Square)	8.5m
Ground Clearance distance	28.02m

Distance between conductors measured perpendicularly	6.0m
Conductor and ground wire's perpendicular distance from one another	9.0m
Conductor Span	400.0m

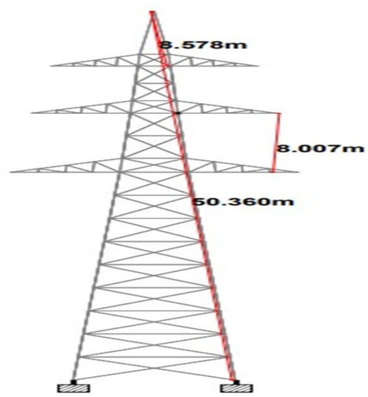

Figure 1: Transmission tower geometry

B. Design Parameters

Each tower member's design and fulfilment of a code check is evaluated in the STAAD software based on the allowed stress design approach, as per IS:802(Part-1/ Sec-1): 1995.

Type of tower	Suspension Tower
Transmission line voltage	400KV
Angle of line deviation	0^o-2^o
Terrain-Type	1
Type of Circuits	Double Circuits
Conductor material “ACSR”	54/7/3.53 mm
Overall diameter of Conductor	31.77 mm
Overall diameter of Ground Wire	10.98 mm
Co-efficient of Linear Expansion(α) in per degree Celsius “ACSR”	$19.3X10^{-6}/^oC$
Elastic modulus(E) in Kg/mm^2 “ACSR”	$7034Kg/mm^2$
Elastic modulus(E) in Kg/mm^2 “GSS”	$19361Kg/mm^2$
Maximal Temperature of conductor	75^oC
Maximal Temperature of Ground wire	53^oC
Everyday Temperature	32^oC
Minimum Temperature	-18^oC
Design Period	100 Years
Type of Peak	Trigonal
Type of Insulator	String

Table 2: Design Parameters

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C. Elevational view of transmission tower

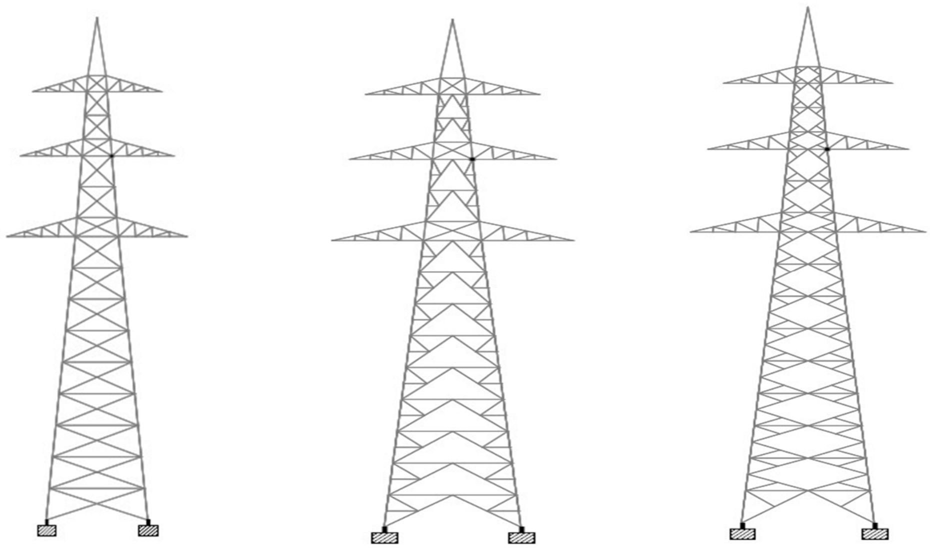

Figure 2: Transmission towers with X, K and D-bracing

D. Design of footing

1) Compressive Load = 149.03KN

2) P_{ult} = 296.92KN

3) Design of Pedestal (Chimney)

- Providing 8 No's of 16mm dia bar.
- Provide 10mm dia bar reinforcement @250mmC/C.

4) Design of Pad footing

- Dimension of footing = 2.5*2.5m

5) Area of steel reinforcement of footing

- Providing 16mm dia bars at 250mm C/C.

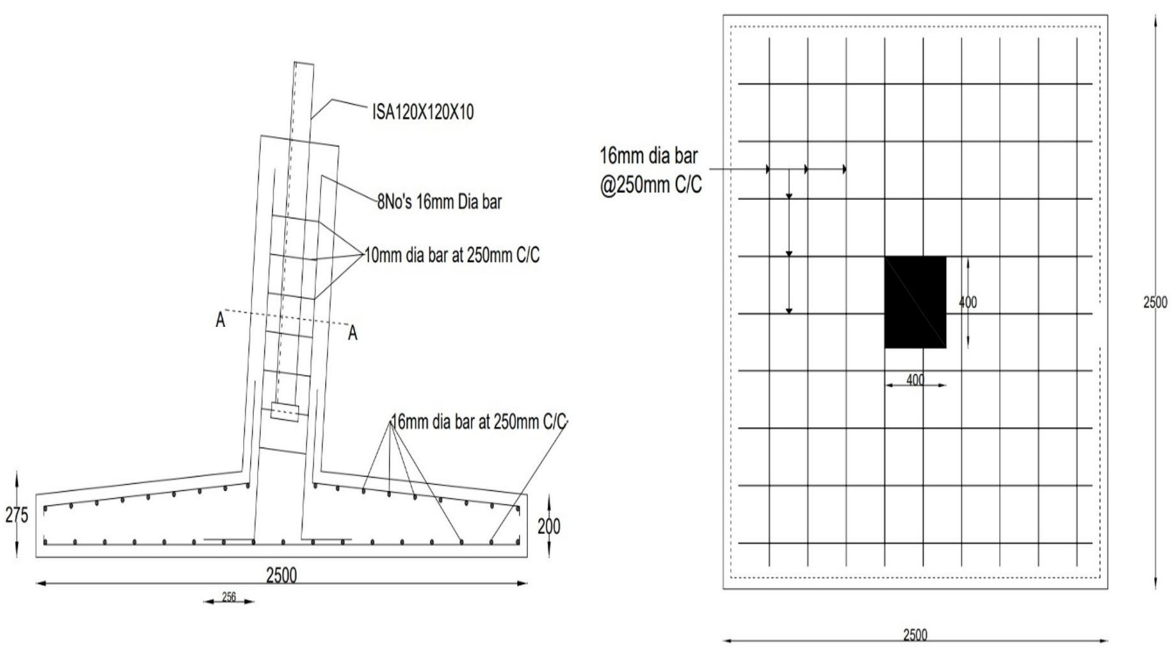

Figure. 3: Reinforcement details of Footing and Pedestal

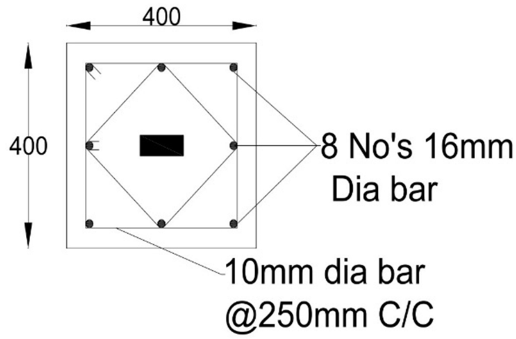

Figure.4: Section at A-A reinforcement details of Pedestal

E. Design of connections

1) Bracing Members (ISA110X110X8)

a) Member force = 7.13KN

b) Shear Capacity of Bolt

Using 4.6 grade bolt of 10mm

V_{dsb} = 22.46KN

c) Bearing capacity of Bolts

V_{dpb} = 27.55KN

d) No. of Bolts = 0.38 ≅ 2 Bolts

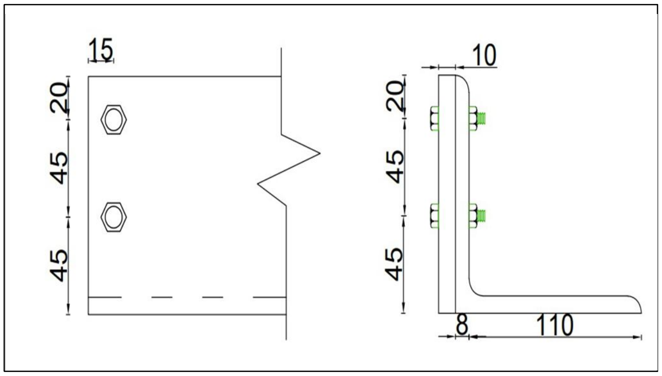

Figure.5: Bolted Connection design of Bracings

2) Horizontal Members (ISA90X90X8)

a) Max Force = 10.89KN

b) Shear Capacity of Bolt

Using 4.6 grade bolt of 10mm

V_{dsb} = 22.46KN

c) Bearing capacity of Bolts

V_{dpb} = 27.55KN

d) No. of Bolts = 0.59 ≅ 2 Bolts

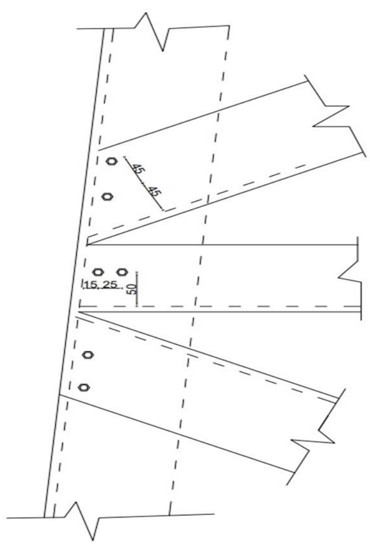

Figure.6: Bolted Connection design of Bracings to Column and Horizontal member to Column

3) Vertical Members (ISA120X120X10)

a) Max Force = 142.69KN

b) Design strength of bolt in Slip Resistance

V_{dsf} = 37.93KN

Let us provide HSFG Bolt of 12mm dia

c) No. of Bolts = 6 Bolts

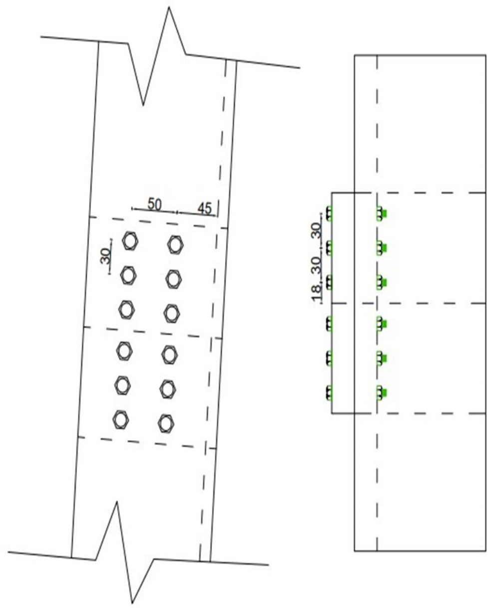

Figure.7: Connection design for Column to Column

V. RESULTS & DISCUSSIONS

A. Height V/s Displacements for X-Bracing in mm

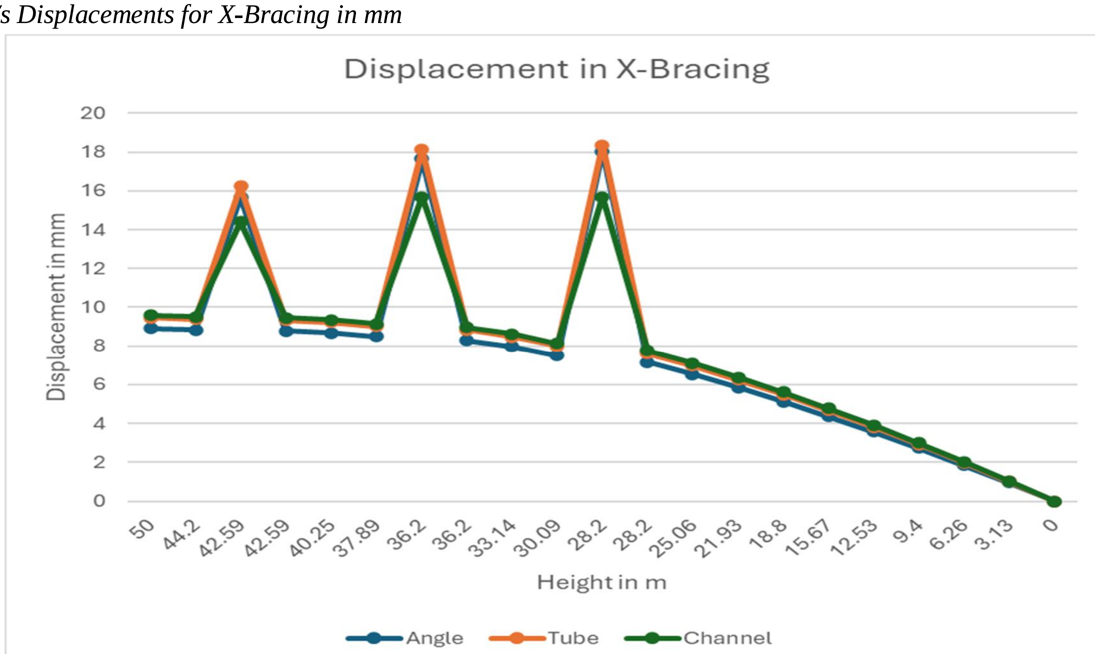

Figure 8: Height V/s Displacement in X-Bracing

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B. Height V/s Displacements for K-Bracing

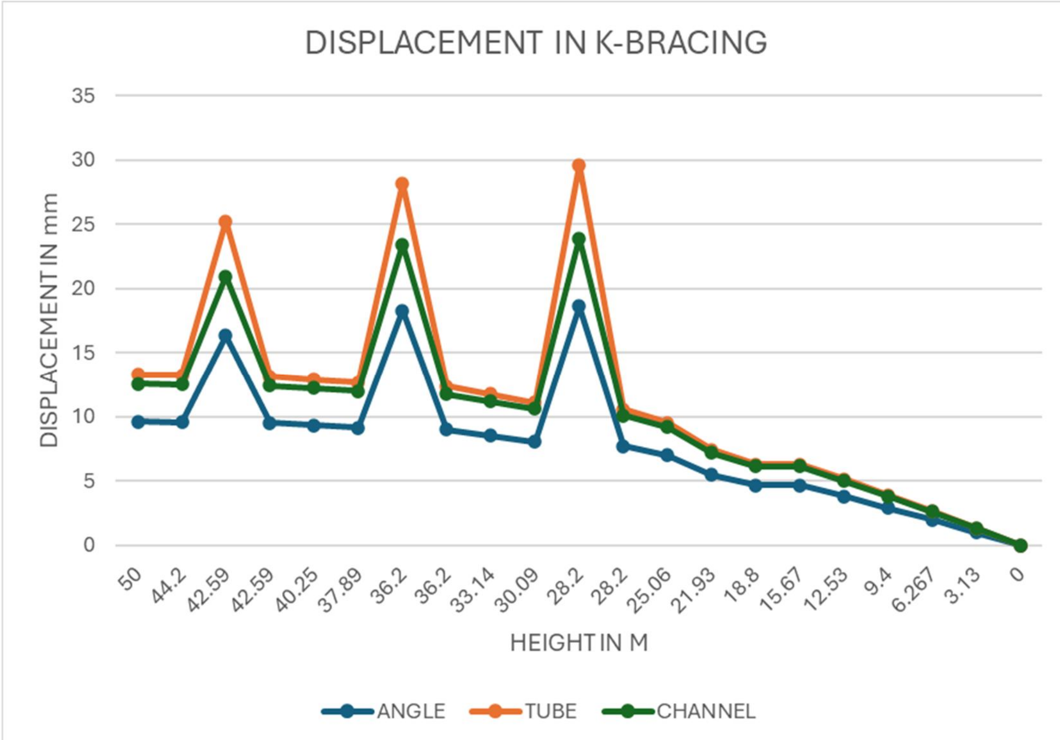

Figure.9: Height V/s Displacement in K-Bracing

C. Height V/s Displacements in D-Bracing

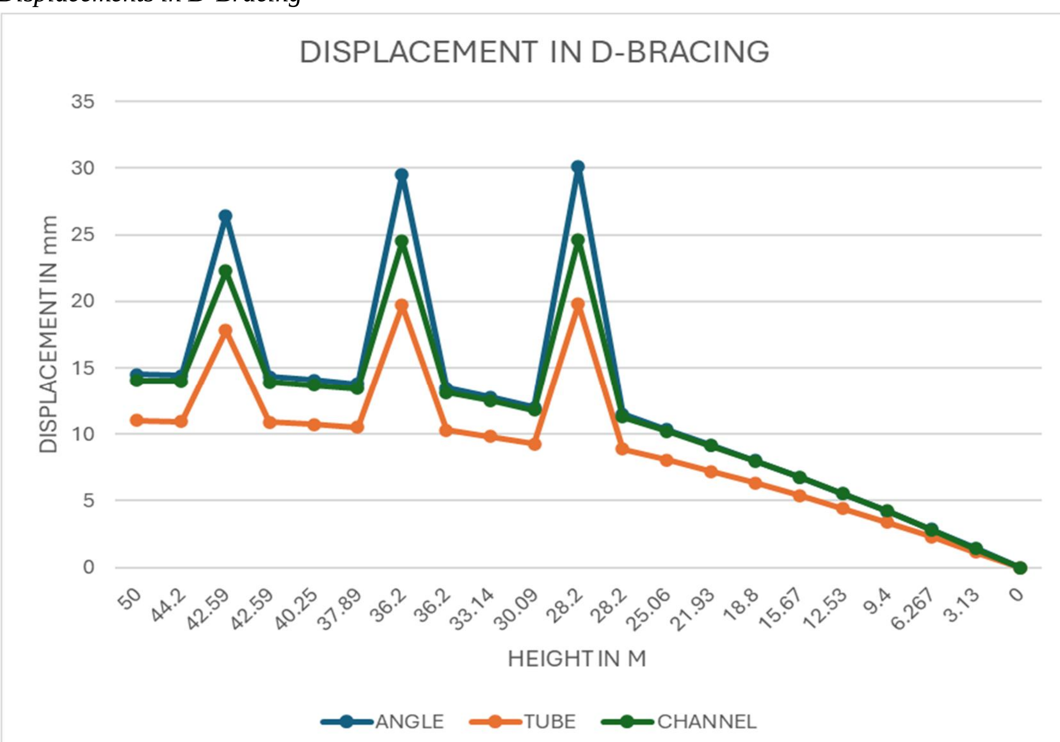

Figure.10: Height V/s Displacement in D-Bracing

The Peak displacement here is noted at cross arms due to load of Conductors and Insulators.

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D. Comparative results of models with X-bracing

PARAMETERS	ANGLE SECTION WITH X-BRACING	TUBE SECTION WITH X-BRACING	CHANNEL SECTION WITH X-BRACING
Node Displacement (Maximum Displacement)	18.05mm	18.35mm	15.96mm
Reaction (Maximum Resultant)	149.03KN	161.62KN	187.32KN
Member Forces (Maximum Axial Forces)	142.69KN	153.92KN	177.37KN
Total Weight of Tower	249.41KN	281.59KN	350.09KN

Table 3: Comparative Results for X-Bracing

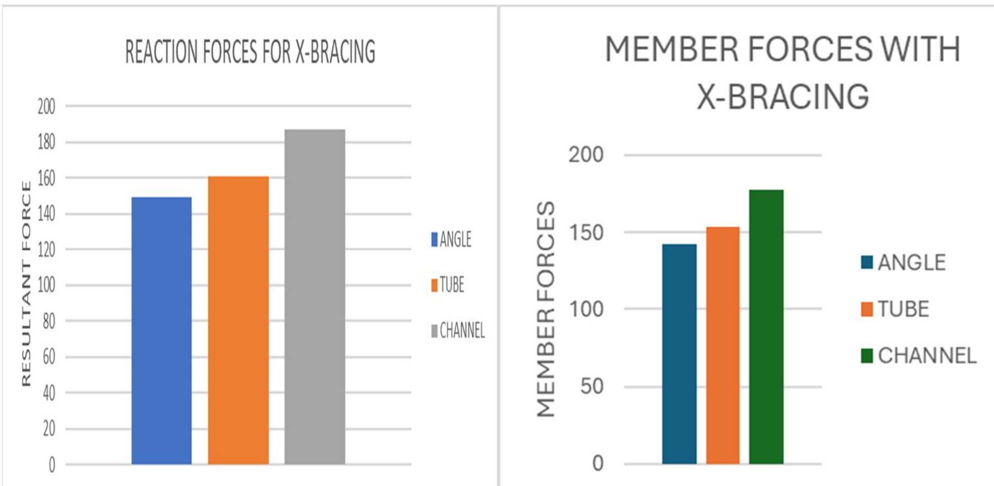

Figure.11: Reaction forces and Maximum member forces for X-Bracing

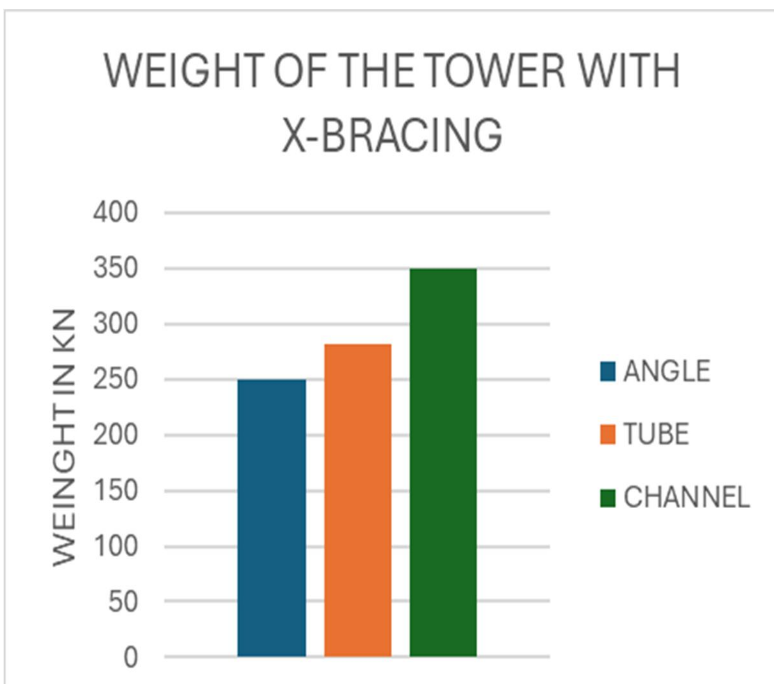

Figure.12: Weight of the tower for X-Bracing

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E. Comparative results of models with K-bracing

PARAMETERS	ANGLE SECTION WITH K-BRACING	TUBE SECTION WITH K-BRACING	CHANNEL SECTION WITH K-BRACING
Node Displacement (Maximum Displacement)	18.64mm	29.62mm	23.911mm
Reaction (Maximum Resultant)	157.69KN	211.93KN	238.89KN
Member Forces (Maximum Axial Forces)	154.01KN	205.73KN	227.36KN
Total Weight of Tower	272.43KN	297.23KN	369.14KN

Table 4: Comparative Results for K-Bracing

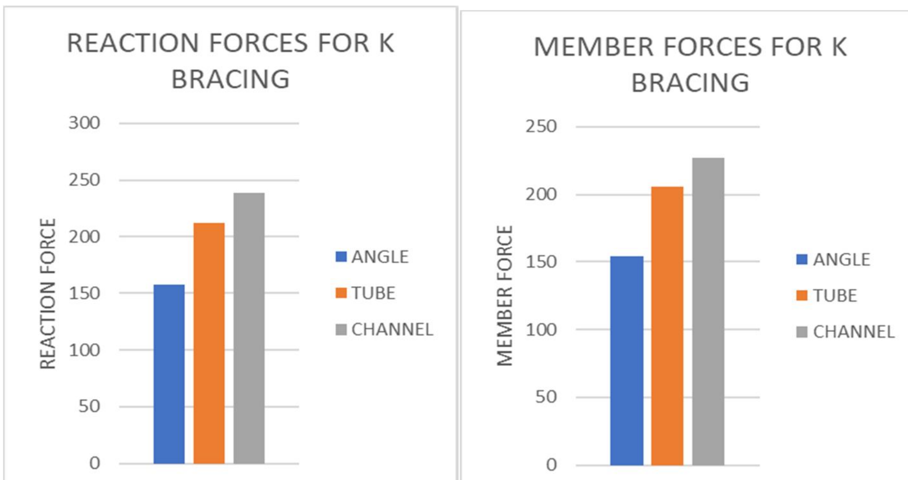


Figure.13: Reaction forces and Maximum member forces for K-Bracing

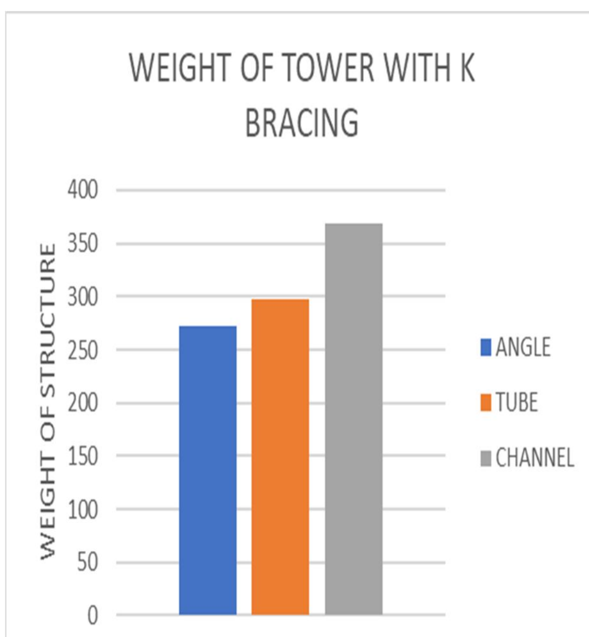
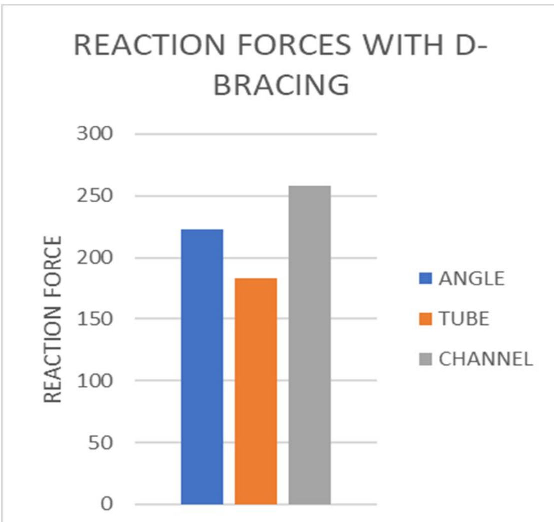


Figure.14: Weight of the tower for K-Bracing

F. *Comparative results of models with d-bracing*

PARAMETERS	ANGLE SECTION WITH D-BRACING	TUBE SECTION WITH D-BRACING	CHANNEL SECTION WITH D-BRACING
Node Displacement (Maximum Displacement)	30.15mm	19.81mm	24.64mm
Reaction (Maximum Resultant)	222.48KN	182.95KN	258.4KN
Member Forces (Maximum Axial Forces)	217.39KN	176KN	246.25KN
Total Weight of Tower	325.36KN	339.95KN	421.15KN

Table 5: Comparative Results for D-Bracing



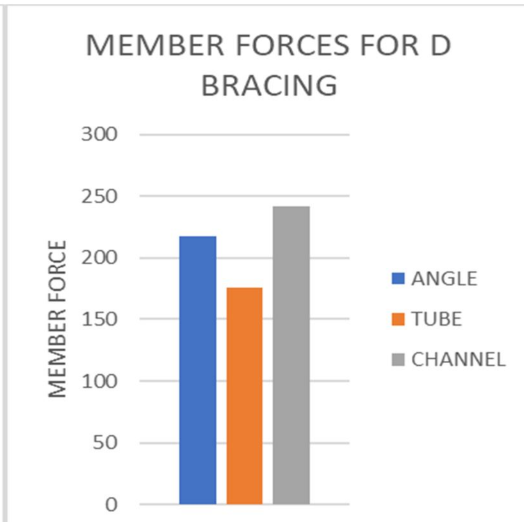


Figure.15: Reaction forces and Maximum member forces for D-Bracing

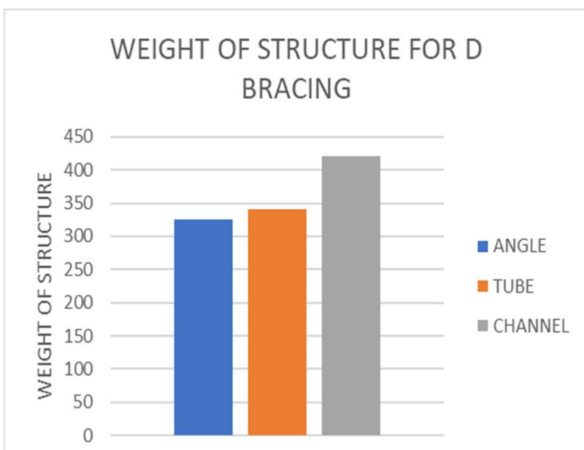


Figure.16: Weight of the tower for D-Bracing

G. *Discussions*

1) Channel sections, being the stiffest, display the least displacement, while tube sections exhibit the highest displacement, indicating lower stiffness. Angle sections offer moderate stiffness, with displacement falling between tube and channel sections.

2) Angle sections experience the lowest resultant and member forces, followed by tube sections. Channel sections endure the highest forces, indicating less efficient load distribution compared to the other two section types.
3) Angle sections are the lightest among the tower types, with tube sections having moderate weight and channel sections being the heaviest. The above scenario applies for bracing configurations X, K, and D.

VI. CONCLUSION

1) Angle sections offer moderate stiffness and lowest member forces, making them efficient and lightweight for X-bracing systems.
2) Across a range of bracing configurations, tube sections offer balanced performance with moderate weight, stiffness, and member forces. However, displacement, member and reaction forces are lowest in tube section with D-bracing.
3) Although channel sections are the stiffest, they have the highest weight, member forces, and inefficient load distribution when used with X, K, or D bracing. Due to these higher forces and weight, channel sections are less optimal.
4) The X-bracing arrangement yields the best results in terms of displacement, member forces, reaction forces, and least amount of structural weight out of all the bracing configurations.
5) Angle sections with X-bracing are the most efficient in terms of displacement, reaction forces, member forces, and overall weight, making them the most economical option for structural design.
6) The reaction forces, member forces, and displacement are most significant under the load combination of dead load (DL) +live load (LL).

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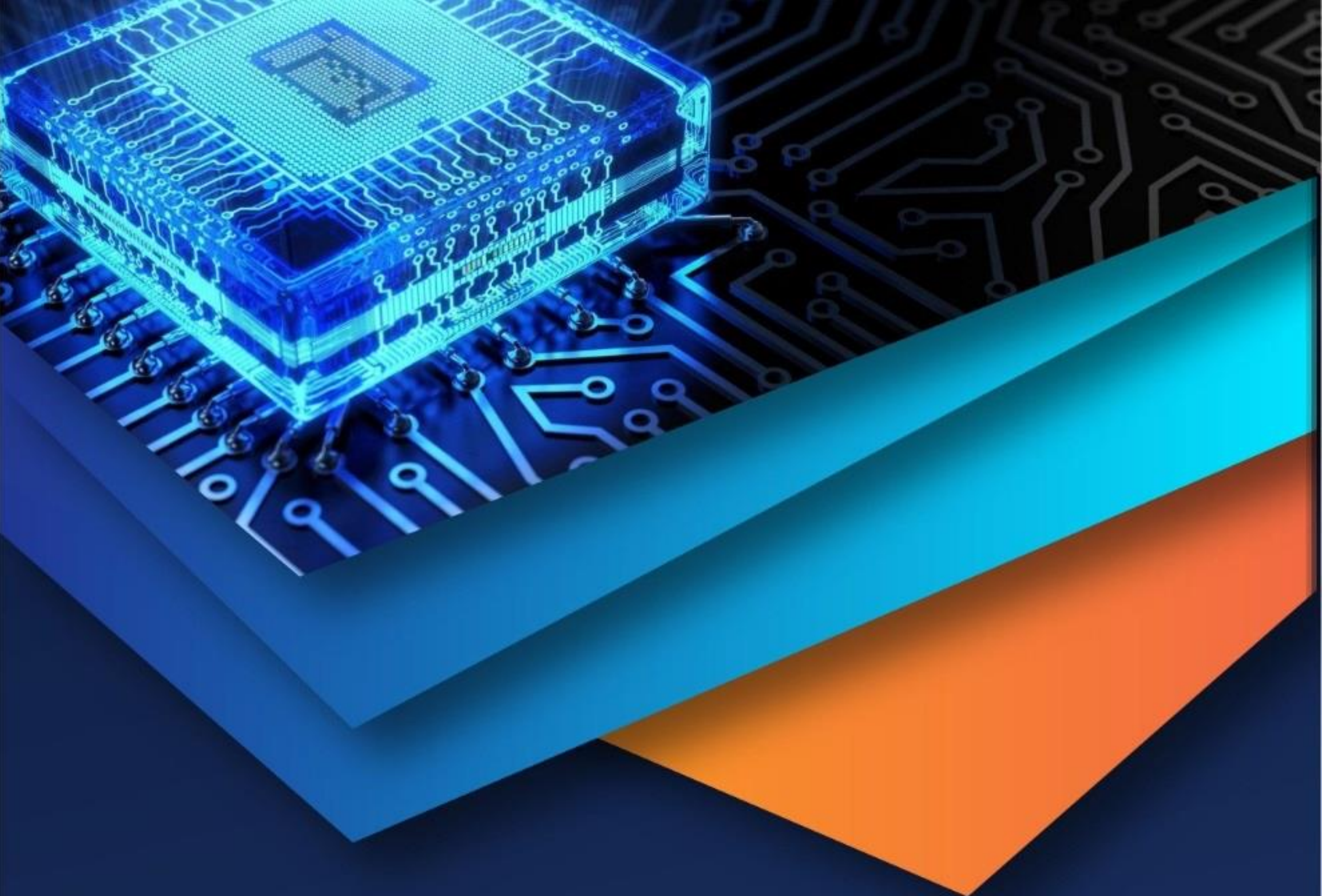
	LIST OF IS CODES REFERRED
1	IS 800:2007: General Construction in Steel - Code of Practice
2	IS 875(Part 3): Wind Loads on Buildings and Structures
3	IS 802(Part 1/Sec 1):1995: (Live Load): Use of Structural Steel in Overhead Transmission Line Towers.
4	IS 5613(Part 3/Sec 1):1989: Code of Practice for Design, Installation and Maintenance for Overhead Power Lines (400kv Lines).
5	IS 398(Part 2): 1996: Aluminum Conductors for Overhead Transmission Purposes – Specification
6	IS 4091-1979: Code of Practice for design and construction of foundations for Transmission line towers and Poles
7	IS 11233-1985: Code of practice for design and construction of radar antenna, microwave and TV tower foundations



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